The Gas State

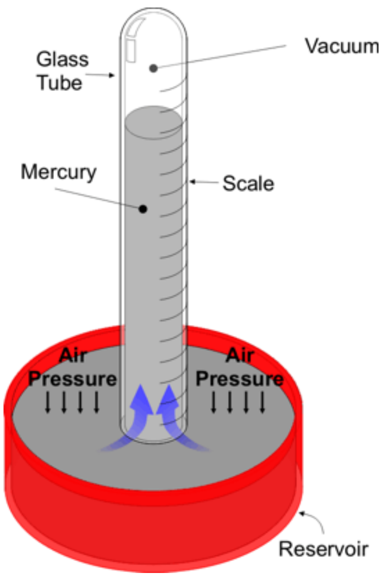
States of Matter

State	**Properties**	**Types of motion**	**Forces**
solid	❍ definite shape and volume ❍ virtually incompressible ❍ do not flow easily	❍ vibrational	❍ very strong intermolecular forces ❍ particles are close together
liquid	❍ assume shape and volume of container (have defined volume) ❍ virtually incompressible ❍ flow readily	❍ rotational ❍ vibrational ❍ translational	❍ relatively strong intermolecular forces ❍ particles are close together
gas	❍ assume shape and volume of container ❍ highly compressible ❍ flow readily	❍ translational ❍ vibrational ❍ rotational	❍ relatively weak intermolecular forces ❍ particles are far apart

Kinetic Molecular Theory (KMT)
- ❍ the idea that all substances contain particles that are in constant, random motion

Gas Laws

Pressure
- movement of gas molecules creates collisions with objects in their paths, particularly walls of a container
- force per unit area (N/m^2)
- SI symbol of pressure is pascal (Pa)



Standard Temperature Pressure (STP)

$0^{o}C$, 101.325 kPa

Standard Ambient Temperature Pressure (SATP)

$25^{o}C$, 100 kPa

Boyle's Law (Robert Boyle)

The **volume** of a specific amount of gas decreases proportionally as the **pressure** on the gas increases, at constant temperature,

$$p \ \alpha \ \frac{1}{v} \ , \ where \ T \ is \ unchanged$$

$$p_1 v_1 = p_2 v_2 \ (Boyle's \ Law)$$

Table: SI and Non-SI Units of Gas Pressure

Unit name	Unit symbol	Definition
pascal	Pa	1 Pa = 1 N/m^2
atmosphere	atm	1 atm = 101.325 kPa
millimetres of mercury	mmHg	760 mmHg = 1 atm = 101.325 kPa
torr	torr	1 torr = 1 mm Hg

More Gas Laws

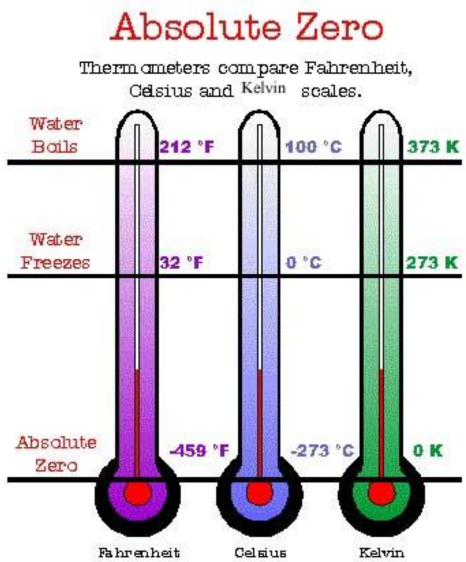
Temperature

- a measure of the motion of gas molecules
- generally measured in degrees Celsius (^{o}C)
- Kelvin temperature scale (K) is based on absolute temperature
- **absolute zero** (point where gas molecules have no motion) is 0 K and/or -273^{o}C

T (K) = T (^{o}C) + 273

For calculations,

STP: 273 K, 101 kPa **SATP**: 298 K, 100 kPa



Charles' Law (Jacques Charles)

The **volume** of a specific amount of gas increases proportionally as the **temperature** on the gas increases, at constant pressure.

$$T \ \alpha \ v \ , \ where \ p \ is \ unchanged$$

$$\frac{v_1}{T_1} = \frac{v_2}{T_2} \ (Charles' \ Law)$$

Gay-Lussac's Law (Joseph Gay-Lussac)

The **pressure** of a specific amount of gas increases proportionally as the **temperature** of the gas increases, at constant volume.

$$p \; \alpha \; T \;\; , \textit{where } v \textit{ is unchanged}$$

$$\frac{p_1}{T_1} = \frac{p_2}{T_2} \; (Gay - Lussac's \, Law)$$

Combined Gas Law

- the relationship between volume, temperature, and pressure for a fixed amount of gas (*n*)

Boyle's law:	$p \; \alpha \; 1/v$	(*T* and *n* are controlled variables)
Charles' law:	$T \; \alpha \; v$	(*p* and *n* are controlled variables)
Gay-Lussac's law:	$p \; \alpha \; T$	(*v* and *n* are controlled variables)

$$pv \; \alpha \; T$$

$$\frac{p_1 v_1}{T_1} = \frac{p_2 v_2}{T_2} \; (Combined \, Gas \, Law)$$

The Ideal Gas Law

All gases will be considered **ideal gases**:

- obey all the gas laws perfectly under all conditions
- do not condense when cooled, gas volume = 0 at absolute zero
- linear graphs of volume/temperature, pressure/temperature, etc.
- gas particles do not attract each other

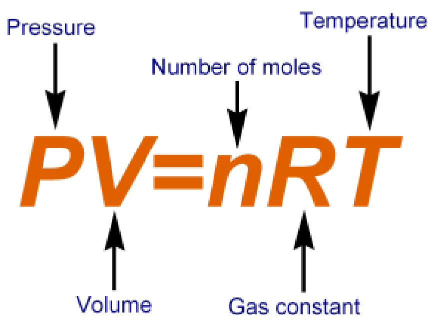
We need to include all four variables (*v*, *p*, *T*, *n*):

$$v \; \alpha \; \frac{1}{p} \; (Boyle's \, Law) \qquad v \; \alpha \; T \; (Charles' \, Law)$$

$$p \; \alpha \; T \; (Gay - Lussac's \, Law) \qquad v \; \alpha \; n \; (common \, sense)$$

$$v \; \alpha \; \frac{1}{p} \times T \times n$$

By introducing a constant, we can state this as an equation,



where R is known as the **gas constant**, which relates

- the pressure (in kPa),
- the volume (in L),
- the amount (in moles),
- and temperature (in K)

of any ideal gas.

$$v = \frac{nRT}{p}$$

OR

$$pv = nRT \; (Ideal\, Gas\, Law)$$

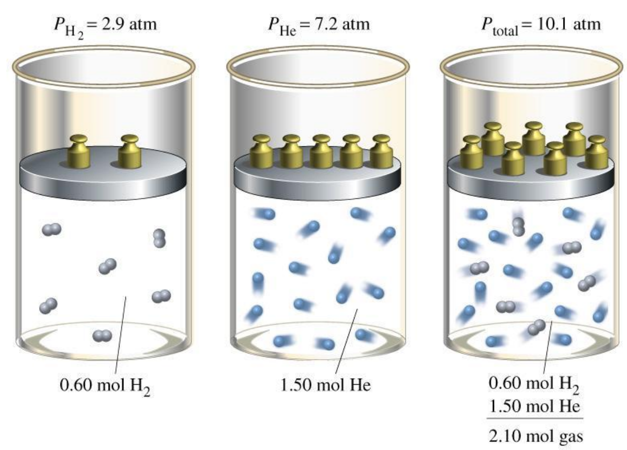
Determine the value of the gas constant, R, given that 1.00 mol of an ideal gas occupies a volume of 22.414 L at STP.

Mixtures of Gases

- Gas particles behave independently of one another.
- The pressure exerted by a particular gas is the same whether it exists by itself or in a gas mixture.

Dalton's law of partial pressures

The total pressure of a mixture of nonreacting gases is equal to the sum of the partial pressures of the individual gases.



$$p_{total} = p_1 + p_2 + p_3 + \ldots$$

partial pressure: the pressure a gas in a mixture would exert if it were the only gas present in the same volume and at the same temperature

- partial pressure of gases can be determined given the total pressure and the composition of gases

The law of partial pressures can be explained using KMT:

- the pressure of a gas is caused by the collisions of molecules with the walls of the container
- gas molecules act independently of each other

Gas Collection

- gases are collected by displacement of water
- water evaporates easily and some vapour is collected with the gas
- the pressure in the container will be equal to atmospheric pressure

Temperature (^{o}C)	19.0	20.0	21.0	22.0	23.0	24.0	25.0
Vapour pressure (kPa)	2.20	2.34	2.49	2.64	2.81	2.98	3.17

Reactions of Gases

- mixtures of some gases will cause reactions

hydrogen gas	+	oxygen gas	→	water vapour
2.0 L		1.0 L		2.0 L
3.0 L		1.5 L		3.0 L
8.0 L		4.0 L		8.0 L

Law of Combining Volumes (Joseph Gay-Lussac)
When measured at the same temperature and pressure, volumes of gaseous reactants and products of chemical reactions are always in simple ratios of whole numbers.

Avagadro's Theory
Equal volumes of gases at the same temperature and pressure contain equal numbers of molecules.

Molar Volume of Gases

- equal volumes of gases contain an equal number of particles (Avogadro's Theory)
- a mole contains Avogadro's number of particles

- equal volumes of gases contain equal amounts in moles of each gas

Molar volume is the volume that one mole, in this case a gas, occupies at a specific temperature and pressure.

- at STP, one mole of an ideal gas occupies 22.4 L
- at SATP one mole of an ideal gas occupies 24.8 L

TABLE 5.2 Molar Volumes for Various Gases at 0°C and 1 atm

Gas	Molar Volume (L)
Oxygen (O_2)	22.397
Nitrogen (N_2)	22.402
Hydrogen (H_2)	22.433
Helium (He)	22.434
Argon (Ar)	22.397
Carbon dioxide (CO_2)	22.260
Ammonia (NH_3)	22.079

$$n = \frac{v}{V}$$

n is amount of moles of the gas (mol)
v is the measured volume of the gas (L)
V is molar volume (22.4 L/mol or 24.8 L/mol)

Gas Stoichiometry

Step 1 Write a balanced chemical equation.

Step 2 List the measurements and conversion factors for the given substance and the one to be calculated.

- convert mass to grams (g)
- convert volume to litres (L)
- convert concentration to mol/L

Step 3 Convert the measurement to an amount in moles using the appropriate conversion factor.

- $n = \frac{m}{M}$ $n = \frac{v}{V}$ $n = cv$

Step 4 Using the mole ratio from the balanced chemical equation, calculate the amount of the other substance.

Step 5 Convert the calculated amount to the final quantity required using the appropriate conversion factor.

- $m = nM$ $v = nV$ $c = \frac{n}{v}$